

**The distributions of the introduced rhodophytes, *Kappaphycus alvarezii* (Doty), *Kappaphycus striatum* Schmitz and *Gracilaria salicornia* and the physical factors correlated with these distributions in Kane'ohe Bay, O'ahu, Hawai'i**

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**Abstract:** The introduced algae, *Kappaphycus alvarezii*, *Kappaphycus striatum* and *Gracilaria salicornia* were studied regarding their spread and factors related to their distributions in Kane'ohe Bay, O'ahu, Hawai'i. *K. alvarezii* and *K. striatum* have spread 5.7 km from their points of introduction in 1976. *G. salicornia* has also spread considerably since its introduction in 1978. Their distributions extend to all sectors of the bay. Water motion and depth were the most important physical factors correlated with their distribution.

## **Introduction**

Kane'ohe Bay is located on the Northeast coast of the island of O'ahu, in the Hawaiian archipelago (Fig. 1). It is the largest embayment in the State of Hawai'i and the most extensively studied. It extends approximately 13 km in length and 4.5 km in width. Two navigable channels penetrate the outer barrier reef, at the northern and southern ends of the bay. The inner bay consists of a lagoon with patch and fringing reefs (Smith *et al.* 1973).

Kane'ohe Bay has been influenced by natural freshwater flooding. Episodic freshwater kills appear to influence the structuring of reef communities (Jokiel *et al.* 1993). The last significant flood event occurred on Dec. 31, 1987. Coral recovery was rapid, as demonstrated by Jokiel *et al.* (1993).

Anthropogenic influences include erosional runoff of terrigenous sediments,

diversion and channelization of streams, changes in the watershed and riparian environment and 25 years of sewage effluent discharge.

During the sewage discharge period into the south section of the bay, a low ratio of photosynthesis to respiration was observed on the benthic perimeter zone of coral reefs. Benthic photosynthesis increased in response to increased water turbidity. Increased respiration rates by benthic filter feeders resulted in low calcification rates for corals (Smith *et al.* 1981).

Diversion of sewage outfalls began in 1977, with the final point-source discharge eliminated by 1986. Substantial decreases in turbidity and nutrient concentration occurred as a direct result of sewage abatement. A corresponding shift in benthic community structure and a decrease in phytoplankton abundance resulted (Hunter and Evans 1995, Laws and Allen 1996).

Despite a population increase in the surrounding watershed, the water quality of Kane'ohe Bay improved, following sewage diversion, from highly eutrophic to relatively oligotrophic conditions (Laws and Allen 1996). This restoration necessitated an all-inclusive survey of benthic communities for comparative purposes.

*Dictyosphaeria cavernosa* (bubble algae) was the dominant alga in the south basin during the sewage-pollution period. According to the transect surveys in 1983, the abundance of the alga was significantly reduced following the sewage diversion, and percent coral cover increased dramatically. While these trends were expected to continue, a follow-up survey in 1990 indicated increased algal cover and a slowed or reversed trend in coral recovery since 1983 (Hunter and Evans 1995).

### **Algal Introductions**

The Hawaiian archipelago is the most isolated in the world. The closest continent lies more than 4,000 km away, and the nearest island group is located 1,600 km from Hawai'i. This geographic isolation has resulted in unique and

distinctive biota. With the advent of human activity came intentional and accidental introductions. Recent introductions can have a devastating impact on native biota due to the vulnerability of many marine ecosystems and the limited range of endemic and indigenous algal species. Non-native species can spread pathogens, alter ecological conditions and physical characteristics of marine ecosystems, create discord and imbalance, change successional positions, compete for resources, and displace native species.

Since 1950 at least eighteen species of macroalgae have been introduced and become established on O'ahu. Commercial and experimental as well as accidental introductions have resulted in the establishment of alien species from several South Pacific locations, Florida, California, and Japan. *Gracilaria salicornia*, *Kappaphycus alvarezii* and *Kappapycus striatum* are among those that have become particularly successful.

Between 1970 and 1978 a number of algal species were established in Kane'ohe Bay (Eldredge 1994). *G. salicornia* was first introduced into Waikiki, located on the south shore of O'ahu, in April 1978 from the Island of Hawai'i. In September 1978 it was introduced into Kane'ohe Bay. *K. alvarezii* (once taxonomically described as *Eucheuma striatum*) was introduced into Honolulu Harbor, located on the south shore of O'ahu, in September 1974 from the Phillipines. *K. alvarezii* was transplanted to several locations on the northwestern reef bordering Moku o Lo'e in Kane'ohe Bay in late 1976 (Russell 1992).

*K. alvarezii*, which lacks a sexual reproductive cycle, reproduces through vegetative fragmentation. Russell (1981) hypothesized that this biological limitation would prevent its dispersal to new areas. According to Russell, the outer boundaries of the distribution of *K. alvarezii*, end at deep water or shallow depressions and it does not cross the channels or dredged reef areas. Russell concluded that *K. alvarezii* is

non-competitive with indigenous algae since it inhabits sand-covered grooves on the reef edge that are not conducive to growth by native species. The last documentation of the distribution of *K. alvarezii* was made 18 years ago.

I have assessed the present distributions of *Kappaphycus spp.* and *Gracilaria salicornia* in Kane'ohe Bay and the physical/chemical factors correlated with these distributions.

The following hypotheses are addressed:

- 1) The distributions of *Kappaphycus spp.* and *Gracilaria salicornia* have not been limited to the areas immediately surrounding the points of introduction.
- 2) The abundances of these introduced species are related to the physical factors such as oxygen, salinity, depth, temperature, water motion, light, nutrient levels and turbidity.

### Study Site

Kane'ohe Bay (Fig.1) consists of a barrier reef with navigable channels crossing the northern and southern ends of the reef, and a lagoon containing patch and fringing reefs behind the barrier reef. The inshore, inner bay and outer bay comprise the major physiographic zones. The inshore zone is composed of the shoreline intertidal zone and the fringing reef. The lagoon and the patch reefs comprise the inner bay. The lagoon is arbitrarily divided into three sectors: Southeast, Central Basin and Northwest. The outer bay zone contains the barrier reef. (Smith et al. 1973).

Seawater is driven shoreward across the barrier reef by wave action. Prevailing tradewinds blow from the NE and E approximately 70% of the time. The side or direction from which the wind is blowing is referred to as the windward side. Being in or facing the direction from which the wind is blowing is referred to as the leeward side. Circulation in the inner bay is determined by bathymetry and driven by

tides and wind and by the inflow across the barrier reef. The southeast sector has more restricted circulation.

Water conditions within the bay range from estuarine to oceanic. Nine perennial streams drain into the bay from the surrounding watershed and have a major influence on water quality. Stream runoff is highly variable. The extensive shallow reef habitat allows freshwater to mix slowly with inshore water (Jokiel *et al.* 1991).

Three reef types can be found in Kane'ohe Bay: fringing reefs, patch reefs and the barrier reef. The surface of the fringing reefs is generally in water less than 1 m in depth. The reefs occur in calm waters along the shoreline. The profile of the fringing reef includes the reef flats which are exposed to extreme environmental conditions. The highest portion of the reef occurs at the outer end of the reef flat. This algal ridge or reef crest is wave-resistant and is often exposed during low tide. A steep dropoff then extends from approximately 1 m to the floor of the lagoon which has a mean depth of 10 m. The reef slope supports a diverse fish community and relative high coral cover, although this varies between sectors because of different environmental conditions.

Seventy-nine patch reefs are located within Kane'ohe Bay. They are concentrated near the channels, and range from 21 to 850 m in diameter. The upper slopes of these patch reefs display the highest percentage of coral cover.

Four geographic zones depict the physical characteristics of the barrier reef. The lagoonward depositional slope, located on the lagoon side of the reef, is composed of calcareous sediments. The back of the reef flat is comprised of calcium carbonate material that is gradually deposited on the lagoon depositional slope. Corals and algae dominate the algal ridge and reef flat, forming a protective zone for the reef and allows water flow towards shore. A near surface high energy zone and

submarine cliff make up the face the seaward reef slope. There is a deeper area for sediment deposition (Jokiel *et al.* 1991).

## **Methods**

### **A. Geographic Extent**

A systematic survey of all accessible areas within Kane'ohe Bay was undertaken using the manta towboard technique which is effective in assessment of broad scale changes in benthic communities.

Using this technique, distribution of these introduced species can rapidly be assessed.

The observer on the manta towboard was towed for approximately two minutes at a steady speed. The towing bridle was connected to a 10 m braided polyethylene tow rope. Two buoys are attached to the tow rope to prevent entanglement and to allow the rope to remain afloat for increased visibility. Preprinted underwater paper is attached to the manta board for recording. The observer was towed parallel to the fringing reef to allow for maximum visibility of the reef slope and reef flat. A constant towing speed was maintained between 1 and 2 knots. Tow direction was standardized with clockwise tows on patch reefs and south to north tows along the fringing reef. The standardization process minimized error for comparative resurveys. Communication between boat operator and observer used hand signals. Identical detailed outline maps of Kane'ohe Bay were placed in the boat and on the manta towboard to allow identification of sections of reef. Starting positions were near prominent geographic features clearly identifiable on the maps. Weather conditions were noted prior to water entry including wind speed, cloud cover and general ocean conditions. Visibility was recorded every ten tows using the secchi disk method.

There are both advantages and disadvantages to the manta towboard technique. The advantages include efficiency in appraisal of site selection to assess their representativeness of large areas. Distribution and abundance of benthic organisms can be estimated in a relatively short time at remote locations. Surveys can be conducted rapidly with this method of visual survey when covering large distances. Kane'ohe Bay is about 12.7 km in length and 4.3 km wide with a total area of 16 sq. miles. The manta towboard survey was completed in 40 hours over a ten day period. However, tow boarding is not suited for areas of limited visibility or deep water, and organisms may be overlooked (English *et al.* 1994).

#### **B. Detailed Surveys of Representative Central Basin Reef Transects**

The Central basin was selected for the second phase of this project. Standard line transects were used to assess the Central Basin's typical physical environments. Two depths were surveyed at each site. It has been suggested that abundance is lower in deeper waters (Russell 1983). Depths of shallow transects were dependent on topography of the reef edge. The deep transects were at 3 m. Three replications of each depth were done to assess internal consistency.

The three reef types typifying Kane'ohe Bay's physical environment were represented : fringing, patch and barrier reefs. The sites selected were representative of these reef types in the Central Basin. Both windward and leeward zones were surveyed on patch reefs.

At each site, three replicate transects of 25-m length were located at each of two depths : shallow (<1 m) and deep (3 m). A 1-m square quadrat was placed at 15 random points (selected from a table of random numbers) along the 25-m transect. Coverage of macroalgae, coral and substrate type was determined visually, using the

10 x10 cm string grid within the quadrat frame.

Later in the summer, six additional sites were added to increase sample size and to allow for inclusion of the top sections of the each patch reefs previously surveyed. Water motion, benthic cover and depth were measured at these sites. Other measurements were not included as they did not show a strong correlation with algal distribution and abundance in the previously surveyed sites.

Water motion was measured three times at each site using plaster of paris clod cards. The diffusion increase factor (DIF) was based on the enhanced dissolution rate of the clod cards in moving water at each site compared to the dissolution rate of control clod cards in motionless water of equal salinity. Clod cards were placed at the sites for a 24 hours. Two replicates were averaged for DIF at each site on each deployment date. An analysis of variance was used to test for significant differences between sites and dates.

Temperature and oxygen were measured using a YSI 55 oxygen meter. Salinity was measured using a YSI SCT meter. A depth gauge was used to determine depth.

Translucent 125-ml bottles were immersed below the water surface to collect nutrient samples. Bottles were promptly placed on ice and frozen within 1-2 hours of collection. Samples were analyzed by School of Ocean and Earth Science Technology (SOEST) Analytical Service using standard methods.

Translucent 250-ml bottles were used to collect Nephelometric Turbidity Units (NTU) samples. Samples were processed within 24 hours of collection using a Turner nephelometer to measure NTU. Opaque one-liter bottles were used to collect subsurface water for determination of total suspended solids (TSS). One liter of water was filtered through a millipore manifold. Suspended solids were collected onto preweighed glass microfiber filters. Total suspended solids were determined from dry



filter weights. The correlation between NTU and TSS measurements was determined.

To determine how the spectral energy of Photosynthetically Active Radiance (PAR) is influenced by depth and turbidity in water, LI-COR integrating quantameters with submersible LI-COR cosine light sensors were used. One light sensor and quantameter were held approximately 5 cm underwater, while an additional LI-COR sensor was lowered to 3 m. Both sensors were calibrated simultaneously in air. Light levels were measured between 1100 and 1400 hours to insure optimum intensity and angle.

### C. Data Analysis

All physical and biological data were analyzed using Cluster Analysis and Principal Components Analysis (PC ORD, version 2.0, 1995). Cluster Analysis was used to identify which sites most closely resemble one another. Principal Components Analysis identified which variables play the most important role in characterizing each cluster. All percent-coverage data were arcsine transformed before data analysis.

## Results

### A. Geographic Extent

The spread of *Gracilaria salicornia* has extended throughout the Southeast Sector (Fig. 2). It has expanded into parts of the Central Basin and occurs in low abundances on the barrier reef.

*Kappaphycus spp.* have also been spreading throughout the bay (Fig. 3). From the points of origin on Moku o Lo'e, they have extended their ranges towards the Southeast Sector and the Central Basin. I found *Kappaphycus spp.* at least 5.7 km from the point of original introduction. It spans the entire Southeast Sector and its

spread is nearly complete in the Central Basin. *Kappaphycus spp.* now occurs in low abundance in the Northeast Sector and on the barrier reef and they appear to be continuing to spread.

#### **B. Detailed Surveys of Representative Central Basin Reef Transects**

On the reef transects the highest abundance of *Kappaphycus striatum* and *K. alvarezii* occurred at the patch reef sites at less than 1m (Table 1). *Gracilaria salicornia* was found on the fringing reef sites at less than 1 m . It did not occur at the other reef zones on the transects.

*Dictyosphaeria cavernosa* occurred in highest abundances at the 3-m depth. Total other algae was highest at the barrier reef sites.

Depth played an important role in the similarity of sites. The 3-m sites were more closely related to each other than the 1-m sites due to high *Dictyosphaeria cavernosa* abundance, low coral cover, low water motion, and low abundance of *K. striatum*, *K. alvarezii* and total other algae (Fig. 7).

Water motion was the major influencing factor in algal distribution. There was a significant negative correlation between diffusion factors and *D. cavernosa* (Pearson correlation coefficient = -0.5663,  $\alpha=0.05$ ) (Fig. 4). There was also a trend towards a negative correlation between water movement and *K. striatum* abundance although it was not statistically significant.

Turbidity was very low at these reef sites (Table 2). Total suspended solids ranged from 17.2 to 19.9 and NTU range from 0.6 to 1.03. There was a weak correlation between TSS and NTU (Pearson correlation coefficient = 0.227, n.s.) (Fig. 5).

For the surveyed depths, light is unlikely to be a limiting factor. Light extinction

values at 3 m showed no significant difference from values at the 1-m depth. Typical extinction coefficients at 1 m were 0.4 and 0.7 at 3 m. Using these extinction coefficients and the published values of light saturation ( $I_k$ ) for *K. alvarezii* of 150  $\mu\text{mol cm}^{-2}\text{s}^{-1}$ , typical winter and summer days were compared. At both depths, similar light intensity patterns emerged (Fig. 6). Algae at both depths are exposed to saturation levels of light for the entire day.

At these sites, nutrients were in the range of levels for Kane'ohe Bay (Laws and Allen 1992, Te 1996, Larned 1996). There were insignificant differences in nutrient levels between sites.

## Discussion

Water motion and depth were the most important physical factors strongly correlated with algal distribution. There was no correlation between the distributions of algae and nutrients or light extinction at the depths and sites surveyed. Oxygen, salinity, temperature and turbidity did not fluctuate greatly between sites.

### A. Geographic Extent

Both *Kappaphycus* spp. and *Gracilaria salicornia* have spread throughout Kane'ohe Bay. Their spread is nearly complete in the Southeast Sector and Central Basin. Although they occur in low abundance in the Northwest Sector and the barrier reef, they have spread into these regions.

It is known that high growth rates, effective propagation, high surface to volume ratios and morphological plasticity can accelerate the spread of introduced species into new areas (Carpenter 1990).

*Kappaphycus* spp. exhibit high growth rates. In productive areas, algae can double their size in 15-30 days or less (Azanza-Corrales *et al.* 1992). *Kappaphycus* spp. encompasses a wide range of environmental factors where high growth rates can occur. In Hawai'i, *Kappaphycus alvarezii* has shown a year round 5% average daily growth rate. Maximum growth rates of 9% were demonstrated in the laboratory in the Phillipines and the field in Hawai'i (Dawes 1994).

*Kappaphycus* has an effective means of propagation. Reproductive plants are rare. Propagules were not known in any species of *Kappaphycus* although in 1994 a new asexual propagule was found (Mairh 1994). In the Phillipines, *Kappaphycus* is cultivated by vegetative regeneration (Azanza-Corrales *et al.* 1992). Vegetative fragmentation is an effective means of dispersal into new areas. Other invading species have disseminated rapidly through asexual means (Kilar 1986, Mshigeni 1978).

Given these characteristics, the distributions of *Kappaphycus* spp. and *Gracilaria salicornia* will probably continue to spread. Water quality characteristics in all sections of Kane'ohe Bay are similar (Laws and Allen 1992). Since neither physical or chemical factors in the environment seem to be limiting, further expansion may be limited only by grazing or suitable available substrate. *Gracilaria bursapastoris* and *G. coronipifolia* depend on a suitable, stable substratum for distribution (Russell 1992).

## **B. Detailed Surveys of Representative Central Basin Reef Transects**

### **Water Motion**

In this survey a strong correlation between water motion and algal distribution was found. This is consistent with other published research. Water motion has been found to be a prime determinant of algal abundance, distribution and productivity (Doty 1971). Glenn (1992) found water motion to be a major physical factor influencing site

fertility.

Water motion facilitates rapid nutrient absorption. It is thought to affect growth rates by decreasing the motionless water surrounding the thallus. This increases the diffusion rate of nutrients and other materials into and out of the thallus (Conover 1968). It provides a continuous supply of nutrients and removes extracellular products. It also favors growth by preventing extreme fluctuations in chemical and physical factors such as pH, temperature, and dissolved gases, such fluctuations can have adverse effects on algae (Glenn 1989). Doty (1971) found higher standing crops and accelerated algal growth with increased current flow and wave action.

*Kappaphycus* species have thick branches. This has been shown to reduce diffusion of materials into the center of the thallus (Glenn 1992). *Kappaphycus* thallus may require greater water motion than algae with thinner thalli.

In field growth studies in Kane'ohe Bay, water motion was the only environmental factor that was consistently correlated with growth rates of *Kappaphycus alvarezii* and *K. striatum*. Maximum growth rates were found at the highest rates of water motion,  $15 \text{ cm s}^{-1}$ . Eighty-one to ninety-eight percent of the variation in growth rates was attributed to water motion. *Kappaphycus alvarezii* had greater growth responses to water motion than *K. striatum* (Glenn 1992).

Different algal species have genetically and environmentally adapted differently to different water motion regimes. Motion that is too great can limit distribution and interfere with metabolic processes (Conover 1968).

Most *Gracilaria* species are found in calm, protected environments, yet current flow and wave action display more surface area to light thus enhancing growth rates in *Gracilaria verrucosa*. Santelices (1977) also found a positive correlation between *Gracilaria coronopifolia* maximum growth and the seasonal winter peak in water

motion on the north and south shores of O'ahu. However, rapid water motion in wave action areas and exposed shores prevents growth of *Acanthophora spicifera* (Russell 1992). Extremely rapid water motion may prevent *Gracilaria salicornia* from spreading further onto the barrier reef and to other areas outside the bay.

### **Temperature, Salinity, Depth and Turbidity**

Glenn (1989) found growth rates of *Kappaphycus alvarezii* were not affected by seasonality, and correlations between growth rates and these environmental variables were low. With a temperature range for productivity between 30 degrees C and 21 degrees C, no evidence of growth limitation emerged at any time during the year (Glenn 1981). Growth rates of *Dictyosphaeria cavernosa* were also found not to vary with temperature in Kane'ohe Bay (Stimson *et al* 1996).

In this study, salinity was relatively constant between 32 and 34 ppt. Russell (1983) found no correlation between *Acanthophora* and salinity, yet salinity below 30 ppt has been shown to have adverse effects on algae. *Kappaphycus* is a stenohaline alga and may prefer reefs farther from freshwater input since these algae were found in higher abundances on the patch reefs than on the fringing reef.

Depth was found to be a limiting factor for all three introduced species. Higher abundances were found at the 1-m depth than the 3-m depth at all major reef types.

In this study no strong correlation emerged between nutrient concentrations and the algal abundance.

Turbidity was poorly correlated with algal distribution. This could be due to low turbidity and high water quality in Kane'ohe Bay.

### **Light Intensity**

For the depths studied, light is unlikely to be a limiting factor. Both depths reach saturating light intensity for these algal species at approximately the same time and maintain saturating light levels for the entire day.

*K. alvarezii* exhibits no photoinhibition at high light intensity although *K. striatum* does (Dawes 1992). Published P-I parameters for *K. alvarezii* and *K. striatum* were similar to other red seaweeds from shallow, subtidal sites (Dawes 1992).

A seasonal trend occurs with the winter maximum being half of the summer maximum (Glenn 1989). It is known that photosynthetic capacity and growth rates declined with decreasing light and depth (Russell 1983). However, given the high water clarity in Kane'ohe Bay (Laws and Allen 1996) and the lack of differences in turbidity at the sites studied, little difference in light extinction with depth was found in this study.

In warm, temperate waters, maximum growth rate in five *Gracilaria* species were correlated with solar irradiance and day length (Conover 1968). Year round, in Kane'ohe Bay, algae are exposed to saturating levels of light for the entire day.

The effects of irradiance vary with depth, light intensity and nitrogen availability. The pigment phycoerythrin is less developed with high light intensity in red algae in general (Doty 1971, Dawes *et al.* 1974) and in *Gracilaria* species in particular.

## Conclusions

*Acanthophora spicifera* and *Hypnea musciformis*, two recent introductions, possess traits that favor them over native species (Carpenter 1990). High growth rates, effective propagation, high surface to volume ratios and morphological plasticity can accelerate their spread. The introduced species studied also possess many of these traits. Russell (1982) stated that *K. alvarezii* appeared non-competitive since it inhabits sandy grooves on the reef edge that are not conducive to growth by native algae. Transects showed *K. alvarezii* to occur on the reef flat as well.

Ecological invasions can spread rapidly and have negative effects on marine ecosystems. Many non-native species have been quite successful in their strategies

to survive. It is critical to understand the effects these species have on the environment, how they spread and the physical, biological and chemical factors that influence their distribution. This will assist in predicting the impact invasive species have on indigenous species and aid in the conservation and management of our reefs.



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Table 1: Average Percent Cover from Transects

	Kappaphycus alvarezii	Kappaphycus striatum	Gracilaria salicornia	Dictyosphaeria cavernosa	Total Other Algae	Total Coral	Sand	Rock	Depth
BR1	0	0.02	0	0.44	80.96	0.02	5.84	12.53	1
BR2	0	0	0	0.44	48.44	1.2	22.58	26.13	1
BR3	0	0.09	0	1.04	49.56	0.29	21.33	27.36	1
BR4	0.67	7.73	3.93	1.09	23.69	4.22	15.93	29.84	1
FRIS	0.13	0	0	8.73	8.78	31.56	16.13	32.38	1
FRID	0	0	0	42.78	0	21.24	15.42	20.11	3
FR2S	0.07	0	5.29	0.44	13.29	0.22	48.42	31.6	1
FR2D	0	0	0	22.49	0	33.56	10.22	33.96	3
FR3S	0.02	0.02	0.73	0.22	9.96	0	51.02	37.58	1
FR3D	0	0	0	0.22	0	38	28.11	33.44	3
FR4S	0	0	0.02	1.59	7.63	0	50.64	40.21	1
FR4D	0	0	0	43.44	0	19.73	4.22	28.02	3
PR15LS	0	8.71	0.02	11.6	10.07	11.48	2.4	51.78	1
PR15LD	0	2.51	0	31.24	4.87	3.42	9.78	50.07	3
PR15WS	0.13	17.6	0.02	23.8	3.84	12.33	0.09	42.33	1
PR15WD	0	3.36	0	48.42	0	1.67	2.42	43.6	3
PR15T	0	0	0	0.06	37.82	3.78	20.59	36.88	1
PR19LS	0	0	0	34.78	5.78	26.76	14.36	23.73	1
PR19LD	0	0	0	39.64	0	4.4	24.49	31.91	3
PR19WS	0	0	0	35.11	2	22.56	9.16	30.98	1
PR19WD	0	0	0	64.43	0	5.97	9.43	20.53	3
PR19T	0	0.25	0	10.07	6.12	11.67	21	59.23	1
PR26LS	0.87	6.78	0	7.62	6.47	33.78	1.36	43.82	1
PR26LD	0.07	0.24	0	45.87	0	18.13	6.78	28.98	3
PR26WS	0.13	7.98	0	28.09	1.98	24.93	0	36.6	1
PR26WD	0.13	7.98	0	28.09	0	0.84	38.18	24.93	3
PR26T	0.87	0	0	7.62	23.11	2.67	61.18	11.13	1

Abbreviations:

PR=Patch Reef  
FR= Fringing Reef  
BR= Barrier Reef  
W= Windward  
L= Leeward  
S= Shallow  
D= Deep  
T= Top

Table 2 - Mean Values of Physical Factors at Reef Sites in Percent

	Diffusion Factor	Total Suspended Solids	Nephlemetric Turbidity Units	Extinction Co- efficient	Total Nitrogen	Total Phosphorus
Barrier Reef 1	16.65	19.9	1.03	0.52	7.63	0.38
Barrier Reef 2	16.85	18.7	1		6.9	0.38
Barrier Reef 3	20.02	18.9	0.8		6.9	0.4
Barrier Reef 4	7.30					
Fringing Reef 1S	12.50	18.4	0.6	1.18	11.32	0.42
Fringing Reef 1D	4.63			0.74		
Fringing Reef 2S	9.48	18.2	0.9	1.2	9.14	0.38
Fringing Reef 2D	2.79			1.78		
Fringing Reef 3S	10.22	17.2	0.8	0.4	9.3	0.34
Fringing Reef 3D	3.32			0.75		
Fringing Reef 4S	8.58					
Fringing Reef 4D	3.55					
Patch Reef 15LS	11.57	17.8	0.7	0.32	8.14	0.36
Patch Reef 15LD	6.7			0.71		
Patch Reef 15 WS	12.12					
Patch Reef 15WD	6.53					
Patch Reef 15T	11.81					
Patch Reef 19LS	11.09	18	0.8	0.41	8.47	0.37
Patch Reef 19LD	5.01			0.71		
Patch Reef 19 WS	12.25					
Patch Reef 19WD	5					
Patch Reef 19T	10.39					
Patch Reef 26LS	11.56	18.2	0.8	0.97	7.68	0.34
Patch Reef 26LD	3.78			0.86		
Patch Reef 26 WS	9.03					
Patch Reef 26WD	3.36					
Patch Reef 26T	9.42					

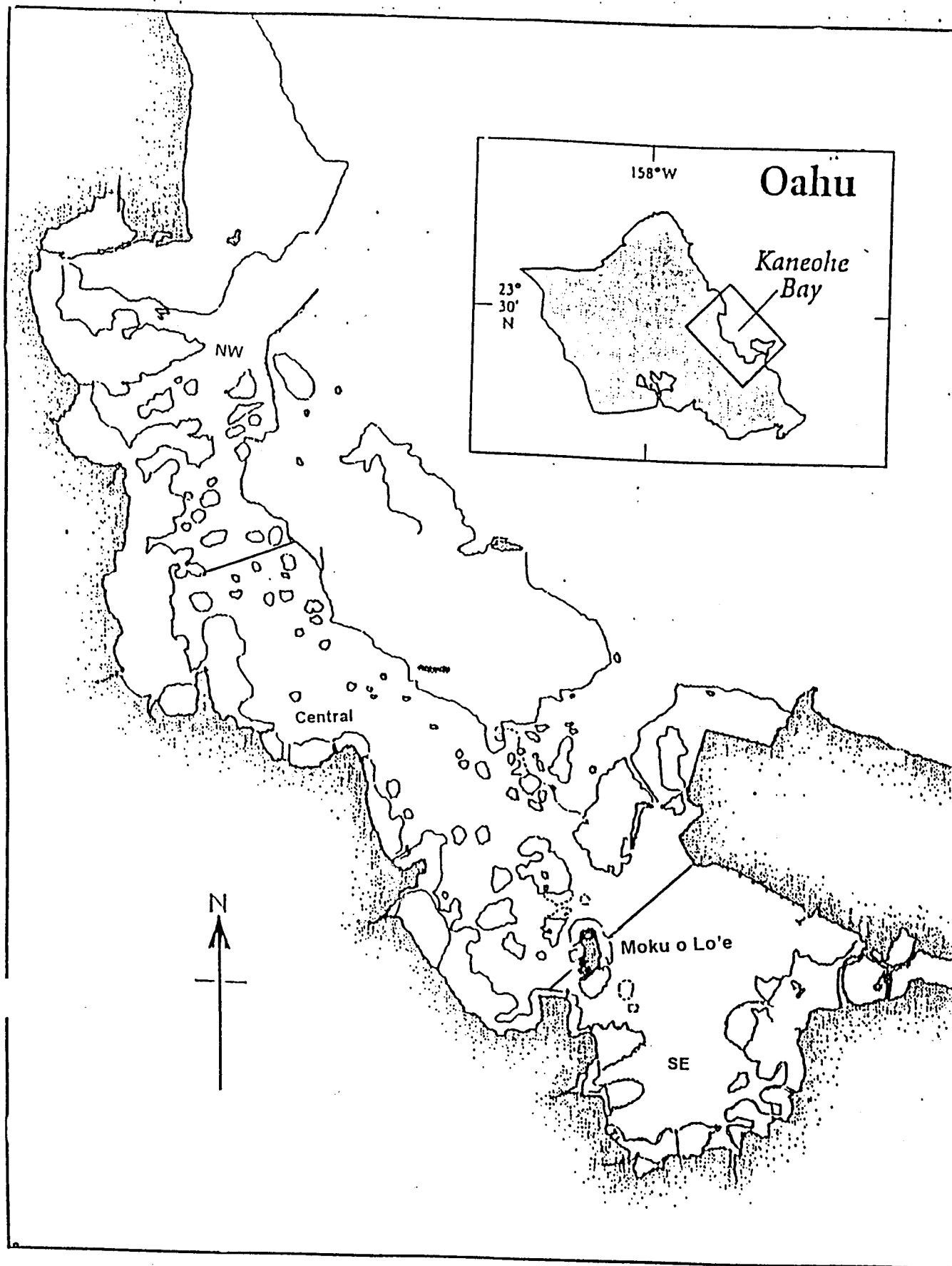


Figure 1 Kāneʻohe Bay Oʻahu, Hawaiʻi

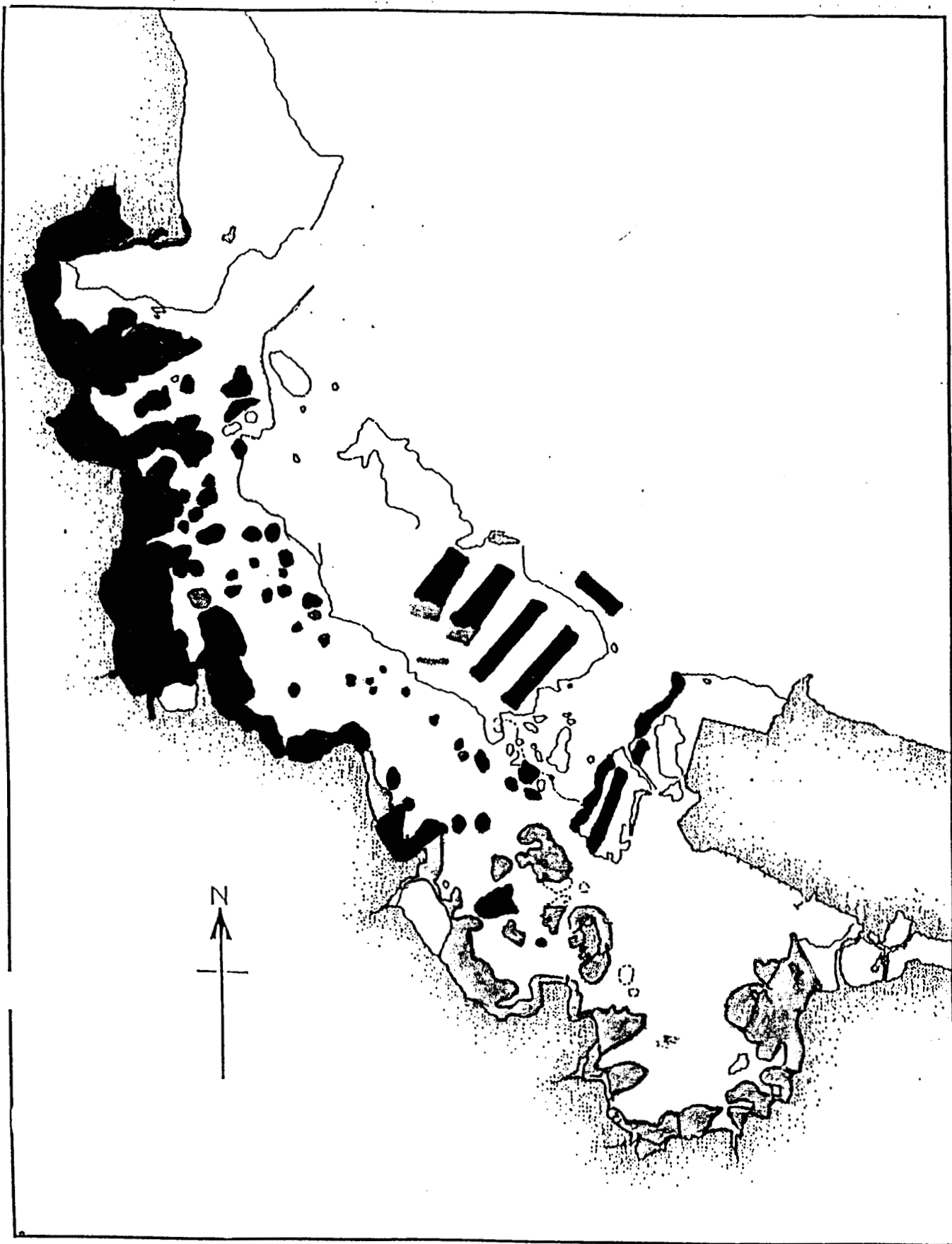


Figure II Distribution of *Gracilaria salicornia* within Kāne'ohe Bay

Red areas=Presence

Blue areas=Absence

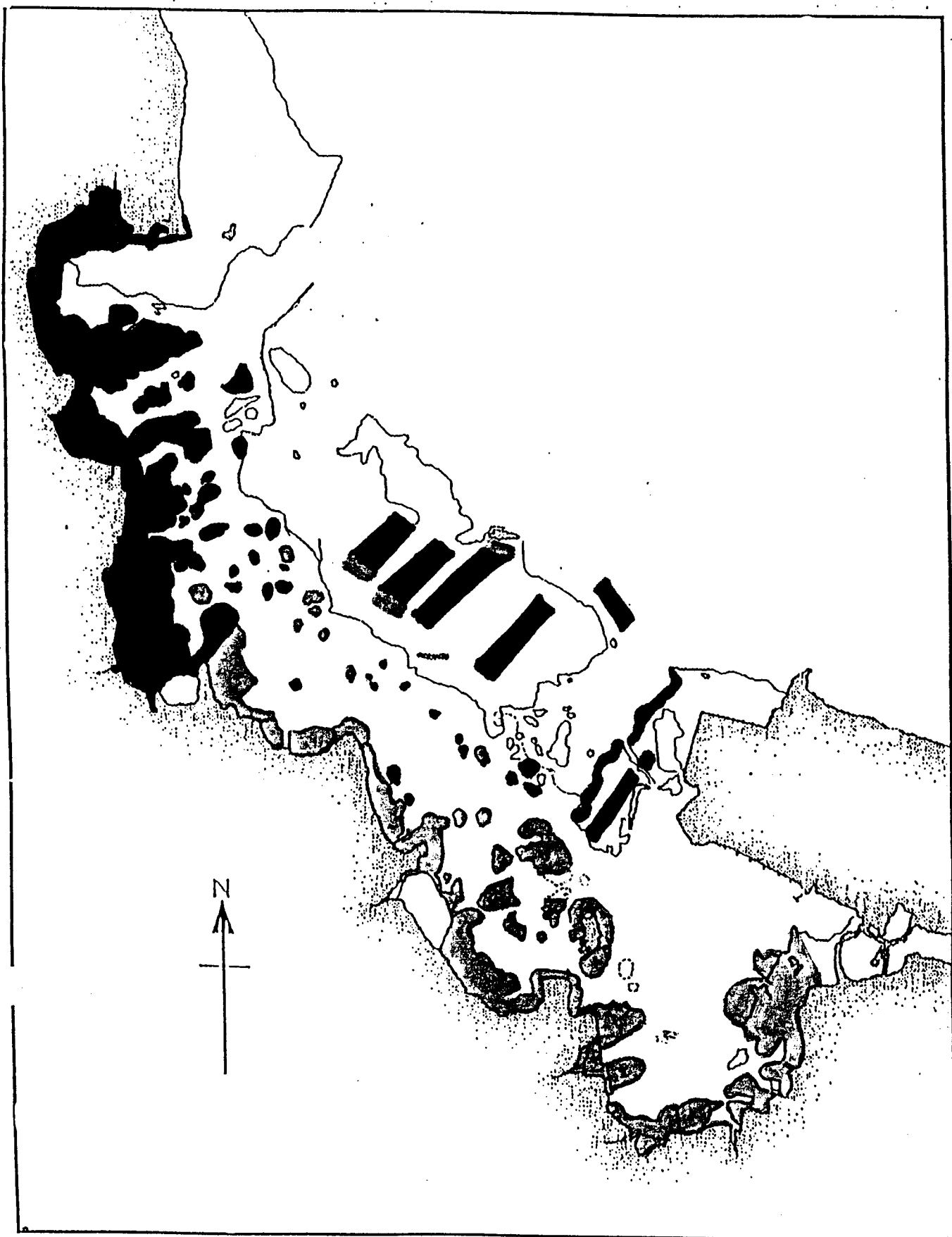


Figure III Distribution of *Kappaphycus* species within Kāne'ohe Bay

Red areas=Presence      Blue areas=Absence



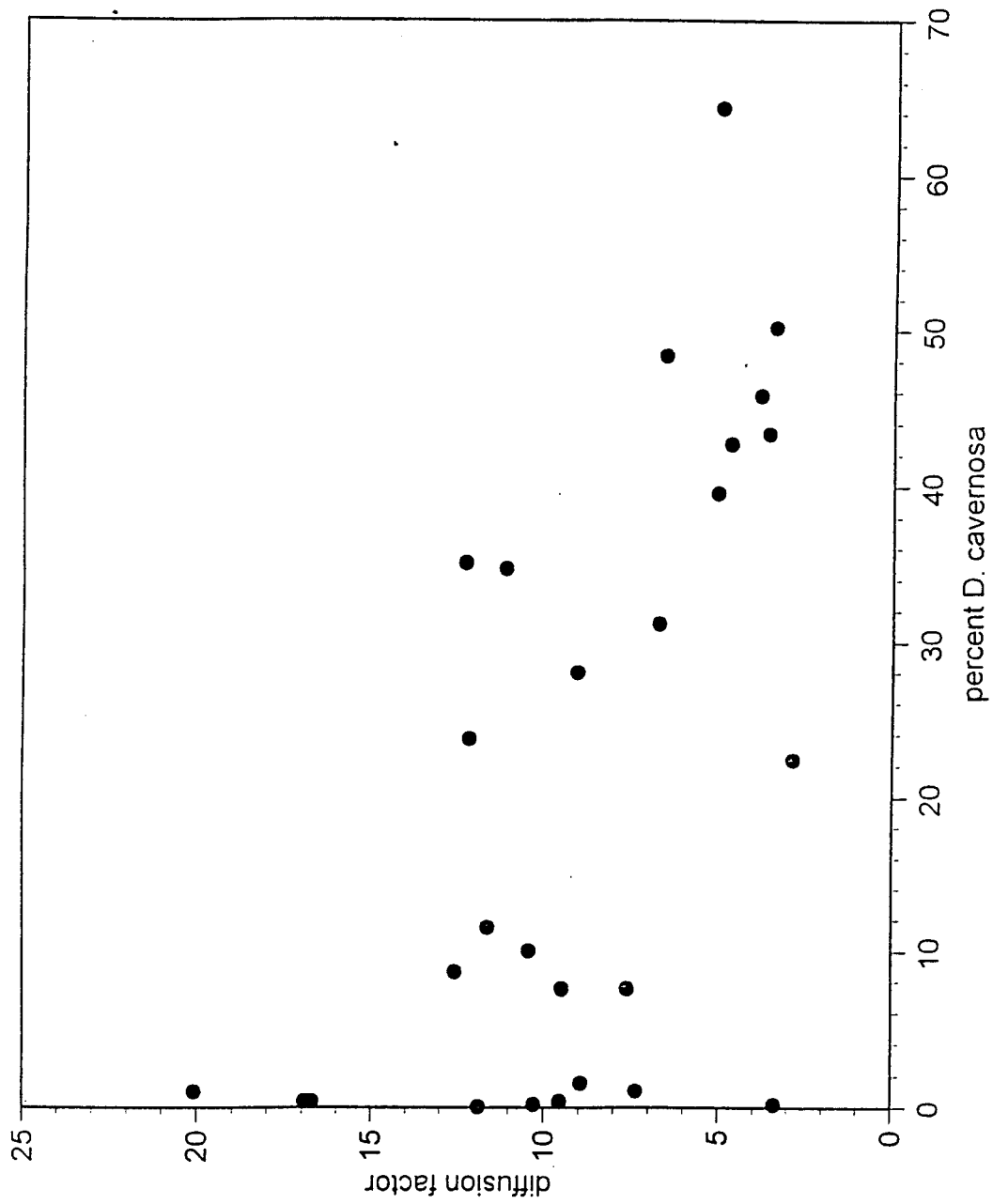


Figure IV: Relationship between percent *Dictyosphaeria cavernosa* and water motion (measured as diffusion factor (DF)) (Pearson correlation =  $-0.5663$ ,  $P < 0.05$ )

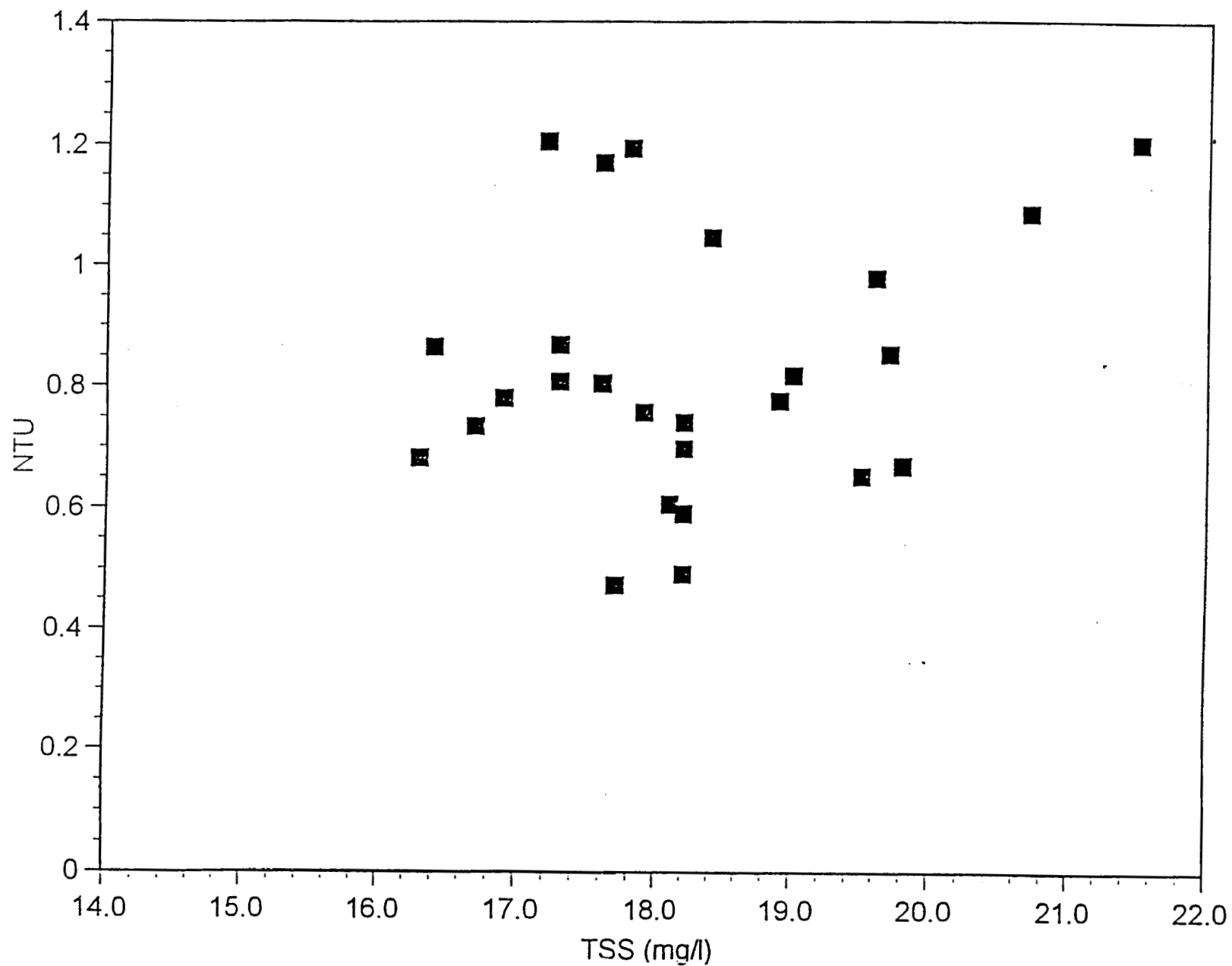
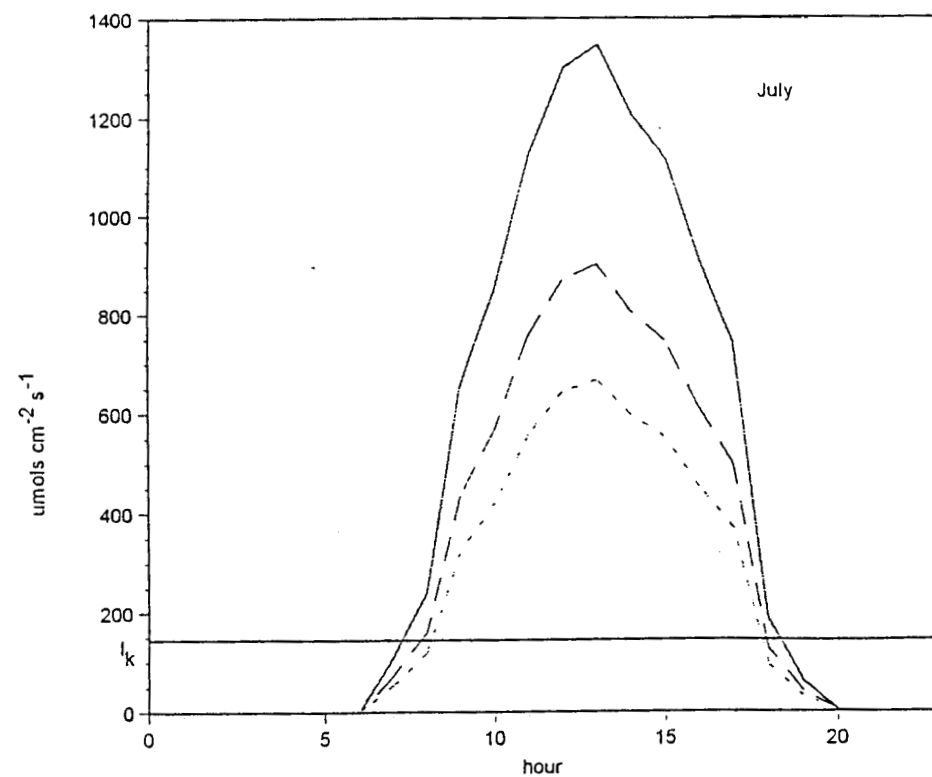
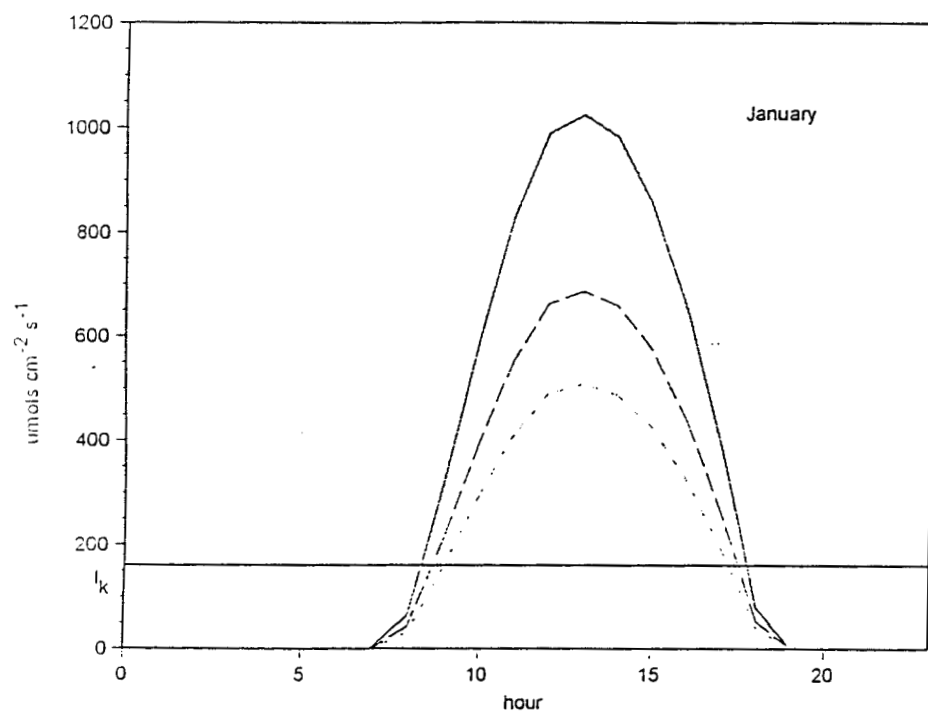


Figure V: Relationship between nephelometric turbidity units (NTU) and total suspended solids (TSS), (Pearson correlation= 0.227, n.s.)

Figure VI Typical profile of photosynthetic active radiance at Moku o Lo'e  
at surface, 1-m, and 3-m depths, January and July 1996.

$I_k$ =saturating light intensity

Data from Hawai'i Institute of Marine Biology weather station



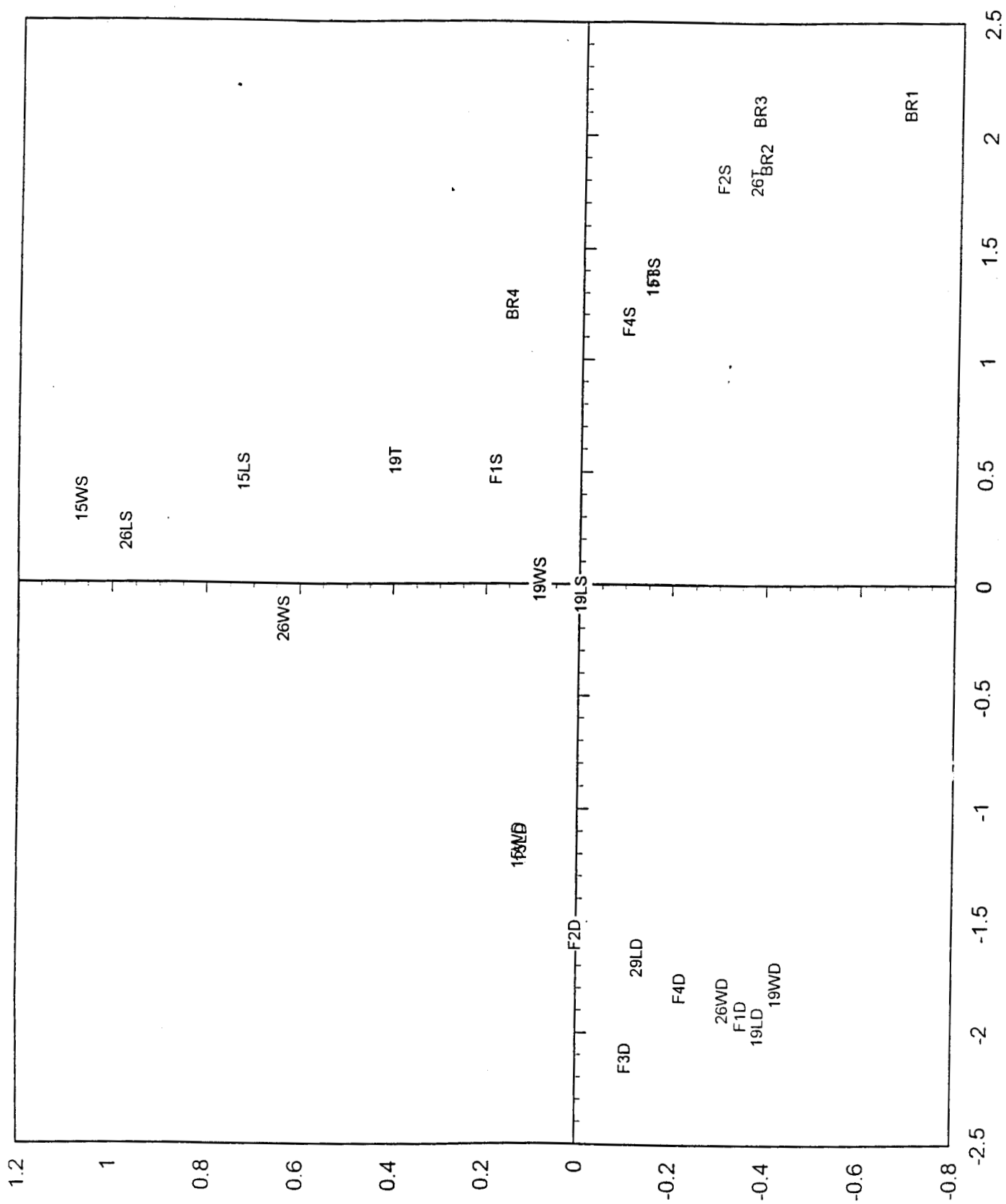


Figure VII Principal Components Analysis of Transect Data  
Abbreviations follow Table I

**National  
Science  
Foundation**

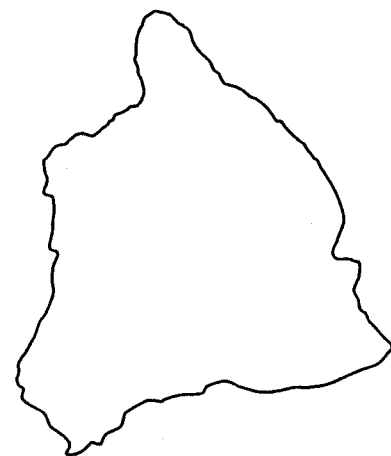
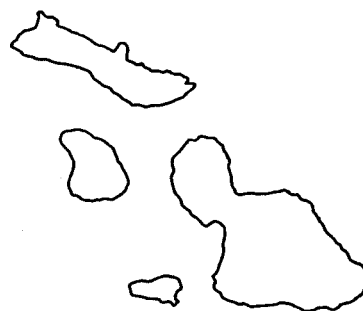
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